Chapter

Amaranth: An Ancient and High-Quality Wholesome Crop

Dinesh Adhikary, Upama Khatri-Chhetri and Jan Slaski

Abstract

Amaranth was a staple of the Aztec diet and is described as a "superfood" in part because of its high protein content and well-balanced amino acid profile. In terms of nutrient content, amaranth surpasses many staple crops such as rice, corn, and wheat. Additionally, lysine content is twice as much than in rice and thrice as much than in corn. Along with desirable agronomic traits, this crop has been hugely applauded for its gluten-free nature. Not only can it benefit vegan and gluten allergy personals, but it also has the potential to supply high-quality proteins and at the same time provides antimicrobial activities in the packaged food items. Despite all of these properties, this crop is still not in the mainstream cultivation practices in North America and in many parts of the world. As the planet is expecting massive increase in human population and global climate change, we firmly believe that this widely distributed, ancient, protein-rich pseudo-cereal has a potential to augment our food system. In this book chapter, we aim to report the nutritional properties of grain amaranth.

Keywords: amaranth, lysine, complete protein, gluten-free, ancient crop

1. Introduction

1.1 *Amaranthus* sp. taxonomy and distribution

Amaranthus L. is a eudicot genus in the Amaranthaceae family of the order Caryophyllales and is commonly known as the pigweeds or amaranths. The genus comprises about 75 species, which are generally annuals, and are distributed throughout the world's temperate and tropical regions [1, 2]. The genus *Amaranthus* is further divided into three subgenera, *Acnida, Albersia*, and *Amaranthus* [3], with *Acnida* being dioecious and subgenera *Albersia* and *Amaranthus* being monoecious but with distinctive floral morphology. The three main domesticated species of *Amaranthus* (*Amaranthus caudatus* L., *A. cruentus* L., and *A. hypochondriacus* L.) originated in the Americas and are primarily cultivated for grain, as potherbs and ornamentals [2, 4].

Amaranth is an ancient crop in which scientific and commercial interest has recently been renewed. The grain amaranths (*A. hypochondriacus*, *A. caudatus*, *A. cruentus*) have many favorable agronomic properties and are highly adaptable to various ecological zones, with better resistance to biotic and abiotic stresses than many conventional other food crops [2]. These species also have advantages of being protein-rich C_4 pseudo-cereals that can be adapted to cultivation in a wide range of environments, with good tolerance of drought and salinity [2, 5]. Amaranths also exhibit superior water use efficiency compared to many other C_3 and C_4 crops [6].

1.2 Amaranth use in the ancient times

The grain amaranth was an important crop for the Aztecs and the Incas [1, 2]. In the pre-Columbian period, it was one of the major crops like beans and corn in the New World and carried religious importance [1]. During the various dates of the religious calendar, Aztec people ground amaranth seeds mixed with honey or human blood and make different shapes of animals, birds, mountains, and gods, and they were eaten during the ceremonies [1, 2].

Prior to the conquest by Spaniards, Mexicans had a culture where a ceremonial paste called *Zoale* was prepared from amaranth grains and was fed to the slaves before they were sacrificed to the gods [1, 7]. From the Christian viewpoint, the use of grain amaranth was the very symbol of heathen idolatry [1], and therefore Spaniards discouraged the cultivation of *Amaranthus* [1, 7]. Although the cultivation was highly suppressed by the Spanish conquistadors, small patches of *A. hypochondriacus* were still grown inside maize fields [1, 2].

Along with the widespread use in food products, grain amaranths also gained religious significance in India and Nepal. In Uttar Pradesh, India, the crop amaranth is recognized as *Ramdana* (seed given by Lord Ram) [7]. In the states of Madhya Pradesh and Gujarat, India, amaranth is recognized as *Rajgira* (*Rajgira*, a seed given by King, an incarnation of Lord Vishnu). In Hindu culture, popped amaranth grain is soaked in milk and is one of the food items permitted to be eaten during religious festivals after a long fasting [2, 7]. In different parts of Nepal, India, and Pakistan, popped amaranth seed is used to make *laddoos* and confections like *alegria* in Mexico. *Laddoos* carries an important religious significance. It is considered a pure food and can be offered to Hindu gods. Around the Nilgiri Hills in India, *Badagas* peoples have a ritual that they offer a basket of puffed amaranths on *Badagas* funeral pyre [7, 8]. Looking at those cultural instances, grain amaranths may have been migrated from the Americas to the Old World only about 500 years ago; but it is quite astonishing to get strong evidences on the connection of amaranth grain to Hindu culture in the Old World.

2. Nutritional facts of amaranths

2.1 Amaranth proteins

Based on the solubility and extractability, there are four major seed storage proteins in plants: albumins, globulins, prolamins, and glutelins. In pseudo-cereals, including amaranth, the major seed storage proteins are composed of albumin, globulin, and glutelin [9–13]. However, there are some reports showing traces of prolamins in some of the amaranth species [10, 12]. Storage proteins accumulate in developing seeds and store nitrogen, carbon, and sulfur [14]. These proteins are hydrolyzed and mobilized during seed germination and early seedling growth [14, 15]. They do not carry any enzymatic functions and are found only in seeds. However, some storage proteins may also be involved in defense or metabolism. These proteins are synthesized in the rough endoplasmic reticulum. As seeds mature, they are collected in the protein bodies that are derived from vacuole [15]. They may also act as a sink for excess nitrogen.

Chief distinction between the major proteins is outlined as follows: albumin storage proteins are water soluble with low molecular weight 10–18 kDa and low isoelectric point between pH 4.0 and 5.0 [16]. Based on the sedimentation coefficients (S_{20w}), albumin has the coefficient of approximately 2S; therefore it is defined as 2S albumin [17]. However, in the case of pseudo-cereals, the sedimentation coefficients of 1.7S comprised of polypeptides with Mr. ranging from 4000 to 20,000, and they are high in sulfur-containing amino acids, including cysteine and methionine [17]. Majority of albumins consists of two polypeptide chains linked by four disulfide bonds [18]. They are found in dicot plants and account for 20–60% of the total proteins in seed [16]. Globulin storage proteins are soluble in salt with their molecular weights in the range of 150–190 kDa [16]. They have an isoelectric point of pH 5–10 [19]. Based on the sedimentation coefficients, (S_{20w}), globulin has the coefficients ranging from 7S to 12S [16]. They lack cysteine residues and lack disulfide bonds [16]. Glutelin storage proteins are soluble in borate buffer but poorly soluble in water. They have molecular weights in the range of 45–150 kDa and an isoelectric point range between the pH range of 4.8 and 8.7 and are highly hydrophobic in nature [16]. They are high in proline and glutamine content [16]. One of the distinctive signal peptides that is distinguished from other storage proteins is the 37 amino acid sequence at the NH_2 terminus that is followed by 269 amino acid acidic subunit (Mr = 32,489) and a 193 amino acid basic unit (Mr = 19,587) [20].

2.2 Lysine content

Amaranth grain and leaves are popular for their nutritional value. Protein content is about 15% in grains [21], and it has a well-balanced amino acid composition with high lysine content [22]. Lysine is the limiting amino acid in most of the cereal crops including wheat, sorghum, and rice, but it is abundant in amaranth; only the first limiting amino acid in amaranth is leucine [21], and it is also abundant in most of our staple food sources. Therefore, amaranth is considered as a complete protein supplier when it is consumed with another cereal.

2.3 Seed properties and nutrient content

Grain amaranth plant produces millions of seeds that are small (≈1 mm) in diameter and has not been analyzed for detailed morphological features [23, 24]. The color of the seeds is highly variable from white, gold, brown, and pink to black [24]. Coons [25] reported that black color is dominant over white and a single gene controls the inheritance. It is possible that the seed coat colors, perisperm type, and seed shape in *Amaranthus* species are controlled by different gene loci. Seed shape changes based on angle of view; in lateral view seeds appear lenticular in shape, and in front view seeds appear circular or obovate [23]. Adhikary [24] reported white-vitreous and white-opaque type of seeds. Although seed shape and size may not have a significant impact in the nutrient content of a seed, some pigmented seeds have been reported to contain different amounts of nutrient components. For instance, [21] reported that pale-colored seeds of *A. caudatus* contain about 14% of protein, 10% of fat, 64% of starch, and 8% of dietary fiber, while black-pigmented seeds were reported to contain 16% of dietary fiber, with lysine concentration ranged between 5.2 and 6.0 g/16 g N in the grains [21]. Moreover, protein digestibility was found to be higher in pale seeds than in the black seeds [21].

Starch is formed by two glucan polymers, amylose and amylopectin [26], and is stored in the perisperm of amaranth seed [27]. Like the grasses, amaranth starch can be classified as either glutinous (waxy) or non-glutinous (starchy) [27]. Non-glutinous (starchy) seeds contain both amylose and amylopectin, and glutinous (waxy) seeds lack amylose [24, 26]. Both perisperm forms are found in all three species of the grain *Amaranthus* [26]. Amaranth seeds contain 65–75% of starch [28], and the digestibility of cooked amaranth seeds resulted in a similar response to white bread; however, flaked and roasted seeds responded with a slightly increased glycemic response [29, 29].

2.4 Squalene content

Squalene is a unique triterpene compound that has a biological and pharmacological importance. Although squalene is an intermediate product in the cholesterol biosynthesis process [30], earlier work has predicted that daily consumption can decrease cholesterol levels [31]. It can inhibit chemically induced breast and colon cancer [32]. There are also evidences of a lower frequency of heart diseases in the Mediterranean region [33], as people in this region consume more olive oil, which is rich in squalene [34]; thus it is believed that squalene consumption in the diet has a positive impact on human health. It originates partly from cholesterol synthesis process and partly from dietary sources such as plant oils or shark liver. Among the different types of plant oils, oil extracted from olive and amaranth has a higher concentration of squalene [34, 35]. Especially, grain amaranths have been suggested as an alternative natural source of squalene. The chemical content in five different accessions of *A. cruentus* was reported in the range of 2.26–5.67% [36]. Furthermore, in other domesticated species, [37] reported 3.6% in *A. hypochondriacus* and 6.1% in *A. tricolor*.

2.5 Gluten-free grain

Amaranthus is a gluten-free grain [38], and hence it is a suitable diet for a person with celiac disease (CD) [39, 40]. CD is an autoimmune condition or inflammatory disease, which affects the small intestine triggered by the gluten protein [41, 42] and can lead to weight loss, fatigue, malabsorption, abdominal pain, vomiting, and diarrhea [43]. The main sources of gluten protein are wheat, barley, and rye [42]. CD patients must follow a strict gluten-free diet, and this can potentially lead to nutrient deficiency [43]. Generally, gluten-free products are made with refined flours and starch and require specific packaging material and frequent use of chemical preservatives [44, 45]. This makes a challenge for both producer and consumer. One of the biggest challenges for food technologist is to enrich the nutritional value of gluten-free products with balanced dietary fibers and proteins [44, 46]. Hence, amaranths can be an alternative to address the challenge. In fact, amaranth has become one of the greatest supplements in gluten-free food commodities to enhance nutritional values [47]. Amaranth contains similar macronutrients as wheat and 2–3 times higher than other gluten free crops [42]. Seed protein of amaranth is greater than cereals and legumes [22]. Besides, amaranth has higher lysine and starch than in other cereals [40]. Monosaccharide composition of dietary fiber present in amaranth is well known [48, 24], and amaranth could serve as a significant source of dietary fiber [48]. Moreover, amaranth has higher fiber and mineral content than other gluten-free grains [21]. In today's context, amaranth is one of the few gluten-free pseudo-cereals that has been used in a wide variety of gluten-free food commodities. Amaranth is usually combined with other gluten-free cereals such as rice, corn, and cassava in a variety of food products. For example, blending of amaranth with other flours such as cassava [46] and rice [47] in pasta formulation and rice and maize in bakery items [49, 42] has been introduced to enhance the nutritional value of the pasta and bakery items [46]. Because of its higher nutritional profile, genetic diversity, and high adaptability, amaranth can be considered as an excellent supplement to produce gluten-free food products.

One of the most common and costly problems affecting bakery products is fungal contamination. Rizzello et al. [45] reported that the use of amaranth in bakery products can enhance antifungal activity in bread. Amaranth seeds contain some antifungal peptides, which can show a defensive response toward pathogenic fungi [50]. It is noteworthy to mention that amaranth is rich in betalain pigment, which has also been shown to exhibit antimicrobial activities. Thus, betalain is a high demand in the food coloring industry. These pigments with a strong hue not only color the food products but also provide strong antimicrobial response. Thus, amaranth can be an excellent natural additive in the food industry.

2.6 Antioxidant properties of amaranth

To date, 75 different betalains have been reported from 17 of the 34 families in the Caryophyllales order [51]. Interestingly, no species outside Caryophyllales has been found to produce betalains naturally [52]. Most species in the Amaranthaceae have detectable betalains in organs including root, stem, leaves, and flowers. The ecological functions of betalains are presumed to include attracting pollinators to flowers and possibly protect vegetative cells from stresses. There is a long-standing speculation that these pigments are involved in response to abiotic and biotic stresses, but evidence in support of this idea is scant.

Red beetroot *(B. vulgaris)* is the only commercial betalain source [52], although amaranths have also been proposed as commercial sources of betalains [53, 54]. These betalains have some limited use in food coloring and also have several reported health benefits [55]. Chemical and biological experiments have demonstrated the antioxidant capacity of betalains [56]. Cai et al. [53] showed that the betalains from Amaranthaceae were stronger antioxidants than ascorbic acid, rutin, and catechins. Betalains have also been reported to have anticancer properties [57]. As these chemicals scavenge free radicals, it is expected that they may help prevent cancer and cardiovascular disease [55]. Sreekanth et al. [58] showed that betalain induces dose- and time-dependent cell deaths of the human chronic myeloid leukemia cell line (K562). Moreover, betalain extract from *A. spinosus* has a significant antimalarial activity in mice [59]. Pigment extract from beetroot pomace also inhibited the growth of gram-negative bacteria [59, 60] and induced zones of reduced growth in *Salmonella typhimurium* and *Bacillus cereus* [61]. Thus, amaranth plant is enriched with both nutritional and nutraceutical properties and is a wholesome crop for the future generation.

3. Concluding remarks

Amaranth was a staple of the Aztec diet and is described now as a “superfood” in part because of its high protein content and balanced amino acid profile. It produces a large number of seeds loaded with high-quality protein components, squalene, lysine, and many other health benefitting nutritional and nutraceutical components. Amaranth grain is gluten-free, which makes it a desirable food crop for millions of peoples all over the world. This widely distributed and protein-rich pseudo-cereal has a potential to support food security. However, this crop is still not in the mainstream cultivation practices in North America and in many parts of the world. With the increasing understanding of molecular and biological information of this crop, there is a strong basis for amaranth to be considered for our future generation. As we are witnessing the massive increase in human population in the next few decades and global climate change, we strongly believe amaranth has a huge potential to support the global food system.

Conflict of interest

All authors have read and approved the manuscript for submission. There is no competing interest.

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